Advanced

# ENGINE RESEARCH

Improving Energy Efficiency

Reducing Emissions

Increasing Durability

Lowering Manufacturing Costs

ARGONNE NATIONAL LABORATORY

# Partnering with Industry at Argonne National Laboratory

The challenge of identifying, tackling, and overcoming transportation-related problems — including those of pollution, energy efficiency, and dwindling natural resources — requires foresight and creativity. Today, working with several industrial partners, Argonne National Laboratory researchers are exploring many innovative advanced engine concepts that will improve energy efficiency and reduce emissions and yet maintain the expected level of performance for automotive engines.

*Committed to improving transportation energy efficiency and reducing emissions, while maintaining high performance.*

# Engine Research Facilities and Capabilities

Argonne's extensive engine research facilities and associated modeling expertise enable a wide range of engine experiments. Argonne also employs the nearby facilities at AutoResearch Laboratories to cost-effectively perform other tests as needed. In addition to its on site facilities, as well as its close proximity to several major vehicle and engine manufacturers, Argonne's Center for Transportation Research has an engineering staff with extensive experience in commercial engine development.

*At AutoResearch Laboratories:*

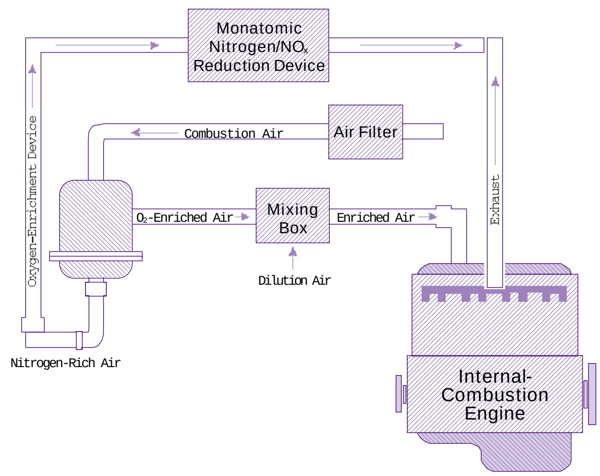
- Automated engine durability test cells
- Chassis-dynamometer setup for Federal Test Procedure and off-cycle emissions analysis
- Exhaust gas measurements, including gas chromatography for hydrocarbon speciation

*At Argonne:*

- Engine-dynamometer test setups to handle 10 to 200 hp engines
- Engine data acquisition system (DSP-Technology's RedLine ADAPT-integrated, real-time control systems for dyno control, data acquisition and combustion analysis)
- In-cylinder piston temperature measurement using microwave and pyrometry techniques
- Nitrogen oxides ($NO_x$) control lab with monatomic nitrogen arc pulser and emissions species analyzers
- Testing and analysis of engine parts with ceramic coatings and advanced lubricants
- Fuel spray (aerosol) systems laboratory with laser diagnostics instruments
- Engine performance mapping and analysis
- Performance codes for diesel and spark-ignition engines
- ANSYS and KIVA codes for analyzing thermal and mechanical loading
- Conventional- and hybrid-vehicle performance and fuel efficiency PC models

# Improvements in Engine Combustion

Argonne has been working with Compact Membrane Systems to develop a low-cost, permeable membrane that would separate ambient air into oxygen-rich and nitrogen-rich streams for use in engines. The membrane (about the size of an air filter) would provide an oxygen stream for the engine to improve combustion, while the nitrogen stream would be fed into the exhaust as a plasma to reduce $NO_X$ emissions.




*For Diesel Engines:*

Problem – Need to meet particulate and smoke emissions standards

Solution – Increasing the in-cylinder concentration of oxygen from the ambient 21% to 25% results in a reduction of almost 60% in particulate emissions at rated load conditions, while engine power output is increased by 50% with only a nominal (15%) increase in peak cylinder pressure.

*For Alternative Fuels:*

Problem – Air toxic emissions for alcohol fuels and low power density for natural gas engines

Solution – With 25% oxygen concentration in the cold phase, experiments show that M85 vehicles can meet CO, NMOG, $NO_X$, and formaldehyde emission standards for TLEV and Tier II. Research also indicates that oxygen enrichment will increase the power density of vehicles powered by natural gas.

*For Gasoline Engines:*

Problem – High hydrocarbon and carbon monoxide emissions during engine cold-start

Solution – Tests show that the proposed California TLEV and Tier II emission standards can be met by using 25% oxygen during the cold phase of the Federal Test Procedure.

## Advanced Sensors for Combustion Control

Argonne has developed an innovative electrocatalytic gas microsensor that is sturdy and inexpensive, operates at several hundred degrees Celsius, and identifies a wide variety of gases and vapors at concentrations approaching 1 ppm. The microsensor's versatility comes from an innovative use of cyclic voltammetry, neural-network signal processing, and ceramic-metallic, or cermet, materials. In principle, the microsensor can measure the concentration of any gas species that reacts with oxygen in its sensing element. The sensor system could provide real-time emission sensing and feedback for advanced combustion control.

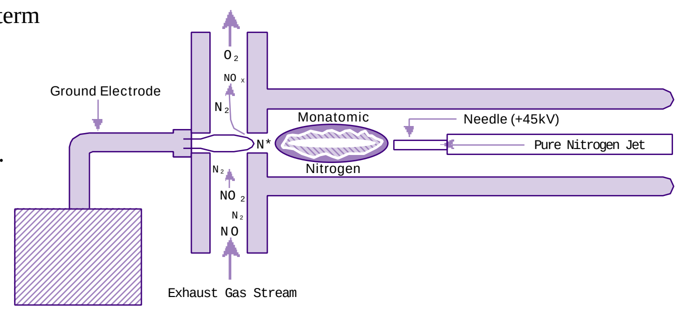
# Control of Nitrogen Oxide Emissions

## Using Catalysts to Control Nitrogen Oxide Emissions from Lean-Burn Engines

In the presence of the excess oxygen found in the exhaust gas from lean-burn engines, the current generation of catalysts is unable to control $NO_X$ emissions. In partnership with the Low Emissions Partnership of the United States Council on Automotive Research, a consortium of the three major automobile manufacturers, Argonne is one of five national laboratories conducting cooperative research on catalysts for $NO_X$ control in the exhaust gas from lean-burn gasoline engines. The selective catalytic reduction (SCR) of $NO_X$ to nitrogen, in the presence of excess oxygen, by unburned hydrocarbons in the exhaust gas appears to be an ideal emission control scheme. The ZSM-5 zeolite charged with copper ions accomplishes this conversion with good efficiency, but it is very susceptible to long-term deactivation under engine exhaust conditions. Argonne is working to understand the factors that promote the effectiveness of this catalyst and to ascertain how they might be replicated in a more durable catalyst material.

## Using Monatomic Nitrogen to Reduce Nitrogen Oxide in Engine Exhaust

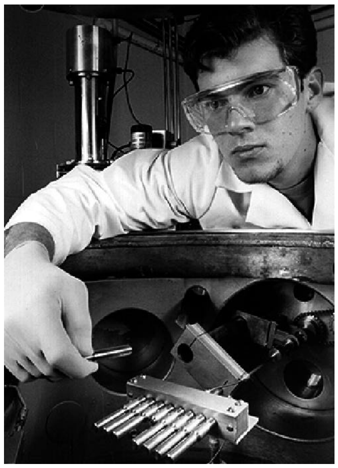
Historically, engine designers have had to live with the trade-offs between control of particulates and $NO_X$ in diesel engines and between $NO_X$ and fuel economy in all engines. This situation is becoming more difficult as the $NO_X$ emissions standard becomes even more stringent. Argonne's success in using monatomic nitrogen plasma to reduce $NO_X$ emissions from gasoline-fueled automotive engines (50-90% reductions of $NO_X$ have been achieved) led Caterpillar, Inc., to fund an evaluation of the concept for heavy-duty diesel engines. It is expected that data from the laboratory evaluation will guide Caterpillar's decision to move this technology to the commercialization phase. A one-of-a-kind facility, the monatomic-nitrogen-generating test bench, is being used in the evaluation.




# Automotive Two-Stroke Engines

Argonne is pursuing advanced engine concepts research with Mercury Marine Division of Brunswick Corporation (Fond du Lac, Wisconsin), a major manufacturer of two-stroke engines. The current CRADA with Mercury Marine is to conduct applied research in materials for automotive two-stroke engines. The components that have been shown to have problems in automotive applications are pistons, rings, bearings, and exhaust ports. The main engine-component stress comes from thermal loads caused by high temperatures encountered in the two-stroke combustion cycle. The ceramic materials development program, sponsored by the U.S. Department of Energy (DOE), has identified a few advanced low-wear, heat-resistant materials that could be used in the form of coatings, composites, or monolithic components to handle high thermal stress.

# Advanced Materials and Lubricants



Advanced engines, such as gas turbines and those fueled by diesel, will operate at elevated temperatures and pressures. These harsh conditions require improved lubricants and coatings for engine durability and reliability.

Problem – Wear and corrosion of fuel injectors using alternative fuels, or injectors under high pressure

Solution – Argonne is working with diesel engines and gas turbines to develop processes for depositing diamond-like coatings on metallic and ceramic components.

Problem – Wear in gears, bearings, drives, and other automotive parts

Solution – A self-replenishing lubricant, boric acid, reduces friction and wear and is environmentally safe.

# “Clean Diesel” Bus Technologies

The use of alternative fuels in city buses could help transit operators meet mandated air quality regulations. However, a large capital investment would be needed to convert the fueling infrastructure and buses. If oxygen-enrichment technology could be applied to meet air quality standards, or if a diesel-electric hybrid system were implemented, the use of these “clean diesel” buses could delay that investment for many years. The Regional Transit Authority in northern Illinois initiated a project with Argonne to evaluate the possibility of applying these technologies to Chicago Transit Authority buses. Following a limited number of engine tests and computer analyses, Argonne concluded that both concepts are practical and could result in a “clean diesel” bus that meets the mandated limits of the Clean Air Act Amendments.

Argonne staff used dedicated models to analyze the performance and emissions of a typical urban bus powered by conventional diesel fuel and an optimized diesel-electric hybrid system. The results compared favorably with published bus data.

| Emissions (g/bhp∗h) | Particulates | Hydro-Carbons | Carbon Monoxide | Oxides of Nitrogen |
|---|---|---|---|---|
| CAA Limit, Transient Test Basis | 0.05[b] | 1.30 | 15.50 | 4.00[c] |
| Current Diesel, 13-Mode Cycle | 0.081 | 0.51 | 0.66 | 9.68 |
| Diesel-Electric Hybrid[a] | 0.04 | 0.45 | 0.50 | 6.70 (4.00)[d] |
| Oxygen-Enriched Diesel, 13-Mode Cycle | 0.05 | 0.51 | 0.54 | 19.20 (3.80)[d] |

*[a]2-mode cycle, idle, full power [b]1996 [c]1998 [d]Estimated values with exhaust gas after-treatment*

## Engine Research Staff in Argonne's Center for Transportation Research

### Robert Larsen

Technology Engineering, Section Leader. M.S., Business, and M.A., Public Policy, University of Wisconsin

- Established DOE's alternative-fuels, cold-weather test fleet at Argonne in 1986
- Responsible for DOE student engineering competitions and the ANL Alternative Motor Fuel Act fleet

### Raj Sekar

Technology Engineering, Deputy Section Leader. M.S., Mechanical Engineering, University of Wisconsin

- Developed and tested diesel engines at Cummins Engine Company for 15 years
- Current work: $O_2$-enrichment, $NO_x$ control, locomotive diesels, and two-stroke engines

### Roy Cuenca

M.S., Mechanical Engineering, Northwestern University

- 20+ years of engine development and business planning in the automotive industry
- At Cummins Engine: advanced engine research, design of the K-6 engine
- Extensive automotive cost analysis experience for industry and government

### Michael Duoba

M.S., Mechanical Engineering, University of Wisconsin

- Emissions from engine cylinder-wall oil film vaporization and bi-polar batteries
- Developed special dynamometer efficiency and emissions tests for HEVs and EVs

### Henry Ng

Ph.D., Combustion and Thermal Sciences, University of Wisconsin

- Evaluated diesel in-cylinder heat transfer at Cummins Engine before joining ANL
- Established the currently operating single-cylinder diesel engine facility at Sandia
- Pioneer in applying fiber-optics in engine combustion research

### Ramesh Poola

Ph.D., Internal Combustion Engines, Indian Institute of Technology

- Experienced in lean-burn SI engines, low-heat rejection engines, and alternative fuels
- Research on high-energy ignitions and scavenging systems for two-stroke engines

### Scott Sluder

M.S., Mechanical Engineering, University of Tennessee

- Experienced in emisions analysis and dynamometer testing
- Research in fuel-injection system optimization and engine calibration

### Frank Stodolsky

M.S., Mechanical Engineering, Catholic University

- 22 years experience in analysis of power systems and their air emissions impacts
- Recent work: slow-speed diesels, coal-fueled diesels, automotive two-stroke engines

### Zhihong Sun

Ph.D., Internal Combustion Engines, University of Minnesota

- Analyzed knock in spark-ignition engines using in-cylinder optical probes
- Evaluated performance of coal slurry fuels in diesel engines

The Argonne engine research team is assisted as needed by other staff from within the Center for Transportation Research; researchers throughout Argonne with specialized expertise in materials, tribology, sensors, and high-performance computing; and our university collaborators.

## Selected and Recent Research Publications

### Engine Research


Poola, R.B., et al., 1995, *Utilizing Intake Air-Oxygen-Enrichment Technology to Reduce Cold-Phase Emissions,* SAE Paper 952420.

Ng, H.K., et al., 1995, *Using Monatomic Nitrogen Induced by a Pulsed Arc to Remove Nitrogen Oxides from a Gas Stream,* ASME Fall Technical Conference.

Assanis, D.N., et al., 1993, *Heat Release Analysis of Oxygen-Enriched Diesel Combustion,* ASME Journal of Engineering for Gas Turbine and Power.

Ng, H.K., et al., 1993, *The Potential Benefits of Intake Air Oxygen Enrichment in Spark Ignition Engine Powered Vehicles,* SAE Paper 932803.

Marr, W.W., R.R. Sekar, R.L. Cole, T.J. Marciniak, and D.E. Longman, 1993, *Oxygen-Enriched Diesel Engine Experiments with a Low-Grade Fuel,* SAE Paper 932805.

Marr, W.W., et al, 1993, *Taguchi Techniques Applied to Oxygen-Enriched Diesel Engine Experiments,* ASME Energy Sources Technology Conference, Paper 93-ICE-3.

Sekar, R.R., and W.W. Marr, 1993, *Bus Application of Oxygen-Enrichment Technology and Diesel-Electric Hybrid Systems,* ANL Report ANL/ESD/TM-58.

Sekar, R.R., et al., 1991, *Oxygen-Enriched Diesel Engine Performance: Comparison of Analytical and Experimental Results,* ASME Journal of Engineering for Gas Turbine and Power.


### Friction and Wear Research


Erdemir, A., et al., *Formation of Ultralow Friction Surface Films on Boron Carbide,* submitted to Applied Physics Letters, Jan. 1996.

Erdemir, A. and G.R. Fenske, *Tribological Performance of Diamond and Diamond-like Carbon Films at Elevated Temperatures,* for presentation at the Annual Meeting of the Society for Tribologists and Lubrication Engineering, 1996.


### Sensor Research

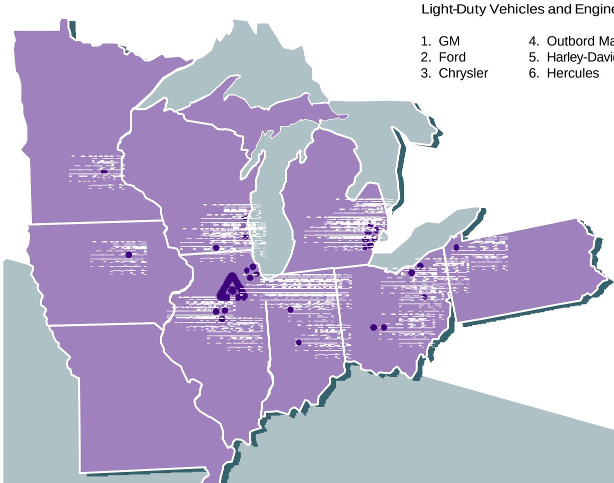

Vogt, M.C., et al, *A Trainable Gas Microsensor Employing Neural Work Technology,* SENSORS, Journal of Applied Sensing Technology, accepted for publication, Dec. 1995.

Iton, L.E., et al., *Alternative Catalyst and Exhaust Gas Sensors,* Proceedings of the Annual Automotive Technology Development Contractors' Coordination Meeting, Dearborn, Mich., 1994.

# ARGONNE NATIONAL LABORATORY

Argonne National Laboratory has forged **successful working partnerships** with major engine and vehicle manufacturers, as well as with universities recognized for their engine research. Argonne's location, in the nation's heartland and industrial center, makes cooperative research easily accessible and cost-effective. Our ongoing research includes work funded by the U.S. Department of Energy (DOE), Cooperative Research and Development Agreements with the auto industry, and work funded solely by engine manufacturers. Argonne, one of the U.S. government's largest research and development laboratories, is committed to research and development leading to **high-quality, cost-effective products** that meet the nation's goals of improving energy efficiency and reducing emissions, as well as the transportation industry's goal of manufacturing **affordable advanced-technology vehicles.** The Laboratory is operated for DOE by the University of Chicago.

Argonne scientists and engineers are leaders in developing **advanced engine technologies, advanced materials and lubricants, sophisticated emissions sensors, alternative fuels, advanced fuel cells, and state-of-the-art energy storage devices.** Argonne also offers expertise in materials recycling and advanced-computing research.



## R&D Centers

**Light-Duty Vehicles and Engines**

1. GM
2. Ford
3. Chrysler
4. Outbord Marine
5. Harley-Davidson
6. Hercules

**Heavy-Duty Engines**

7. Navistar
8. EMD
9. Caterpillar
10. Cummins
11. Cooper
12. General Electric
13. DDC
14. Fairbanks-Morse
15. Waukesha
16. John Deer
17. ONAN

**Fuels**

18. Amoco
19. ADM
20. Pekin Energy Systems
21. Lubrizol

**Trade Associations**

23. EMA
24. AAMA

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